A Solution for Removing Automotive Radar Interference: Radar Communications

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I. Research Question and Overview of State-of-the-Art

Automotive radar is becoming an indispensable equipment in modern cars, for different functions including lane keeping, speed control and parking, especially due to its immunity to bad weather conditions [1]. Likewise, vehicle-to-vehicle (V2V) communication is on the way to become a standard, having proven its value in dissemination of safety critical information [2]. However, the widespread use of both technologies lead to problems, cutting short future plans for autonomous driving and safety. Increased penetration rate and density of automotive radars lead to increased mutual interference, which in turn result with reduced detection probability and ghost detections [3]. Similarly, Omni-directional V2V communication transmissions result in high interference with an increased number of vehicles [4]. This interference leads to packet losses, especially in emergency situations when many vehicles emit warning messages, in turn affecting system-wide safety.

Radar Communication (RadCom) is an approach to use radar hardware for communication purposes and can be used as a means to control and coordinate radar through communication. The combination of communication and radar has been proposed a number of times in various forms and applications [5], [6]. Most works consider orthogonal frequency division multiplexing (OFDM) for joint radar communications [7]–[10]. OFDM is widely used in communication due to its high degree of flexibility, low receiver complexity, and high performance under different propagation conditions [11], [12]. However, due to the low-rate analog-to-digital convertor (ADCs), OFDM cannot fully occupy the radar band (77-81 GHz), limiting its applicability.

II. Method

We propose an FMCW-based RadCom approach, since (1) FMCW can utilize 76–81 GHz [13] radar badnwidth, which provides a high range resolution on the order of centimeters [1] and (2) FMCW radars have a simple and robust hardware, which make them so widespread. Our RadCom approach frequency division multiplexes radar and communication (FDM), where communication is built on a decentralized p-persistent carrier sense multiple access (cCSMA) protocol and is used to adjust the timing of radar transmissions with a time division multiple access for radar signals (rTDMA). Fig. 1 illustrates the division of the frequency and time domains for the proposed FDM/rTDMA/cCSMA based RadCom system. The total bandwidth B is divided into a radar band B_r and a communication bandwidth B_c, for which $B_r + B_c \leq B$ and $B_c < 1/2T_s$, where T_s is the ADC sampling rate in order to be able to reuse the radar ADC. One radar frame duration is divided into time slots T_i of length $(N+1)T$, which corresponds to the duration for sending N chirps plus one chirp time T. This slotted time is set to provide non-overlapping chirp sequences and thereby maximize the number of vehicles with no mutual interference in the RadCom system, defined by $M_{\max}$. V2V communication, taking place in a separate frequency channel of bandwidth B_c, is used to coordinate the starting time of radar frames. Each a communication packet (a fixed number of bytes with a fixed modulation format) is broadcast advertising the starting time of the first chirp in the next time slot T_i. Other vehicles receiving this packet adjust their starting time by selecting a frame starting time for radar transmissions (rTDMA) according to the vulnerable period V, which is the period vulnerable to mutual radar interference. Vehicles, which resolve contention during time slot T_{i-1}, send their radar signals in slot T_i with non-overlapping vulnerable periods. During the communication slot T_i, time is further assumed to be subdivided into slots for p-persistent CSMA operations employed.

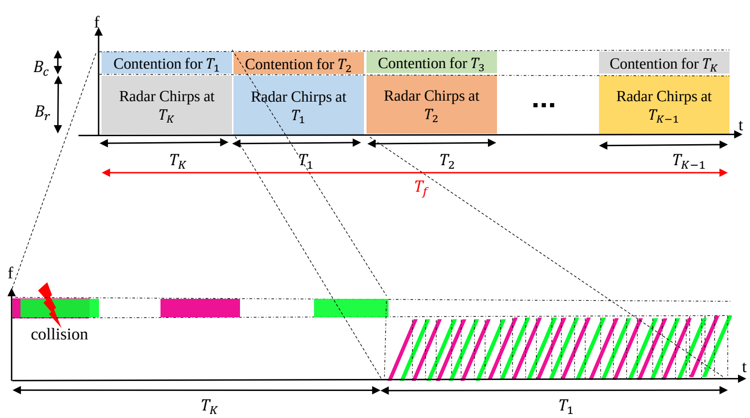

Fig. 1. RadCom scheme: FDM / rTDMA / cCSMA. Radar starting times during slot T_i are determined by p-peristent CSMA contentions that take place in slot T_{i-1}.

III. Analysis and Results

Two automotive radars interfere if their chirp sequences overlap in time so that the starting time of the chirps lie within the vulnerable period V, where $V \approx [-3T/(BT_s), T/(2BT_s)]$ and corresponds to a mutual interference probability of $P_{\text{int}} = 2NT/(BT_s T_f)$. This may lead to a mutual interference with probability as high as 0.25-0.7 for an autonomous radar (for vehicle separation distances of 5 m and one radar per vehicle).

Denoting the duration of the vulnerable period by $|V|$, for the proposed rTDMA, at most $\lfloor T/|V| \rfloor$ different vehicle radars can coexist in a slot T_i and the maximum number of time slots per frame is $K = \lfloor T_f/(N+1)T \rfloor$, which limit $M_{\max}$ under perfect communication by $M_{\max} \leq K \lfloor T/|V| \rfloor$. The proposed communication method of RadCom is shown to solve contention within a reasonable delay smaller than one frame time T_f among $M_{\max}$ vehicles, proving the applicability of the proposed RadCom approach.

The performance of an FMCW receiver under the illumination of another vehicle with FMCW radar is investigated with and without a pedestrian. A comparison is made among the pure radar case and the proposed FMCW-based RadCom case in terms of the probability of false alarm and the ranging error. RadCom is observed to eliminate mutual interference totally with negligible loss in range accuracy. The probability of detection of a pedestrian is also investigated under presence of mutual interference. The vulnerable period is shown to be not affected by the interference signal reflected by the obstacles/pedestrians. Mutual interference is shown to increase SNR of received radar signal, decreasing the pedestrian detection probability; whereas the proposed RadCom approach is observed to remove the interference and detect the pedestrian with probability 1 for various cases.

IV. Conclusion

We have evaluated a RadCom approach building on a combination of FDM, TDMA for radar, and CSMA for communication. The approach exploits the low utilization of time and frequency of a typical radar, as well as the limited impact of a small bandwidth loss on the radar performance. We have performed an interference analysis at both the link and network level and found that with higher penetration, interference is prevalent. We have quantified under which conditions ghost targets occur and evaluated a RadCom scheme which reduces interference by adjusting the radar time over a dedicated V2V band, while reusing the radar hardware for communication. With our proposed approach, we are able to mitigate interference by shifting radar transmissions in time. Performance in terms of probability of interference, pedestrian detection probability, and ranging accuracy are reported, based on high-fidelity simulations. With our proposed approach, by time multiplexing radar transmissions of FMCW automotive radars, we are able to mitigate interference and increase pedestrian detection probability without significantly affecting pedestrian ranging error. It is shown that detection of vehicles and pedestrians degrades in the presence of mutual interference and RadCom can eliminate radar interference with negligible impact in the ranging error. Future work will consider larger-scale scenarios.

Acknowledgment

This work was supported, in part, by Marie Curie Individual Fellowships (H2020-MSCA-IF-2016), Grant 745706 (GreenLoc), and a SEED grant from Electrical Engineering Department of Chalmers University of Technology.

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